FINAL REPORT

INTERNALLY SEALED CONCRETE FOR BRIDGE DECK PROTECTION

by

Celik Ozyildirim
Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This study investigated the characteristics of internally sealed concrete through tests on specimens fabricated in the laboratory to determine its properties and an installation in a bridge deck to assess the controls needed during construction and its performance over five years, the last four under traffic.

Air-entrained samples prepared in the laboratory and obtained from the field during construction provided satisfactory strength and adequate freeze-thaw durability, and prevented or minimized the penetration of chlorides. However, the heat treatment of the deck led to numerous cracks which have facilitated penetration of chlorides to the level of the reinforcing steel and reduced the effectiveness of this protective system.

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INTRODUCTION

One major cause of deterioration of reinforced, hydraulic cement concrete bridge decks is corrosion of the reinforcing steel, which can result in spalling and delaminations. This corrosion is initiated and accelerated by the intrusion of chloride ions, usually from deicing salts, into the concrete and their buildup at the interface of the concrete and the reinforcing steel. One method proposed by the Federal Highway Administration (FHWA) to protect the steel is to use internally sealed concrete (ISC). ISC is produced by adding small, spherical particles of wax to the concrete during batching. After the concrete hardens, it is heated to cause the wax to melt and flow into voids such as capillaries and bleed channels. Upon removal of the heat, the wax hardens in the voids, thus rendering them discontinuous and blocking the intrusion of chemicals into the concrete.(1)

PURPOSE

The purpose of this study was to extend the body of knowledge concerning internally sealed concrete by conducting —

1. a laboratory determination of the properties of the wax and concrete;

2. a field evaluation of a method of heat treatment; and

3. a comparative evaluation of deck structures with and without internally sealed concrete at the time of construction and after the first, third, and fifth winter seasons.

SCOPE

A laboratory investigation of the compressive strength, freeze-thaw resistance, bond strength, absorption, and resistance to chloride penetration of the ISC was conducted. Also, control specimens were prepared and the characteristics of the control and ISC concretes at the fresh and hardened stages were determined.

In September 1977, ISC was placed as a bridge overlay on a 3-span bridge carrying eastbound traffic on I-64 in Alleghany County to protect the reinforcing steel from corrosion. The deck of the adjacent 3-span bridge carrying westbound traffic was constructed as a control and contained epoxy coated bars. The ISC was heat treated in October 1977, using electric blankets. Four evaluations of the condition of the bridge decks were made over a period of 5 years.

LABORATORY EVALUATION

The laboratory investigation of the ISC was detailed in Tyson's interim report of July 1978.(2) The wax beads are a blend of 25% montan and 75% paraffin waxes and range in diameter from 0.007 to 0.033 in. (0.18 to 0.85 mm). While the upper melting point of the beads was found to be 165°F (74°C), a target temperature of 185°F (85°C) was used in heat treating the hardened concretes to assure complete melting of the beads and the required flow into the voids.

The laboratory concrete had a cement content of 635 lb./yd.^{3} (377 kg/m^3), a water cement ratio of 0.47, and wax content of 114 lb./yd.^{3} (68 kg/m^3), which is 7.8% of the mixture by volume. Some of the ISC batches were non-air-entrained and some had from 4% to 6% entrained air. Control batches were prepared without wax or air entrainment. Some specimens were heat treated in an oven and others under an electric blanket.

Petrographic examinations of the heated ISC showed that about 77% of the wax flowed into and sealed the paste regions that had surrounded the unmelted beads. In addition to the petrographic examinations, absorption tests and 90 days of continuous ponding with 2% sodium chloride indicated that this system can be effective in preventing the intrusion of chlorides.

The resistance of the ISC containing air entrainment to damage from cycles of freezing and thawing was adequate, but that for the ISC and control concretes without air entrainment was not. The tests were conducted in accordance with ASTM C666, except that 2% NaCl was used in the test water and the specimens were cured 2 weeks moist and 1 week dry. The heated specimens showed an approximately 5% average loss in compressive strength. The bond strengths developed between the base layer concretes and ISC overlays, as measured by a shear test, were satisfactory, with all the average strength values exhibiting 320 psi (2.2 MPa) and above.

Petrographic examinations of polished sections of specimens that had been heated in the oven revealed cracks that were not visible to the unaided eye. The cracking was more severe for specimens containing gravel as the coarse aggregate than for specimens containing crushed limestone.

FIELD INSTALLATION

The field installation was described in some detail in Tyson's interim report no. 1.(2) The ISC was used as a 2-in. (50-mm) overlay on a new bridge deck. The concrete proportions used in the laboratory were tried in the first batch, except that the water-cement ratio (w/c) was increased to 0.51 to achieve the desired workability. The FHWA had suggested a maximum w/c of 0.55;(3) however, for the remaining five batches of the installation adequate workability was attained using a w/c of 0.47, which was achieved by increasing the cement content from 635 lb./yd.^{3} (377 kg/m^3) to 752 lb./yd.^{3} (446 kg/m^3). Crushed limestone was used as the coarse aggregate in the ISC. The samples obtained from the field concretes were essentially identical to the lab specimens in regard to wax distribution, compressive strength, water absorption, and freezing and thawing resistance. A satisfactory bond was achieved without using a bonding agent between the ISC and the base concrete.

The heat treatment of the overlay, which was the primary concern in the field investigation, was accomplished using the FHWA's electric blanket system and following the FHWA guidelines. Because of the limited coverage of the blankets, the deck was heated in 6 segments. A zone of transition was provided along the edge of the heated areas. This system was developed by the FHWA as a means of heating the concrete to the required temperature without any significant harmful effects on the material or the structure.(1) However, fine cracks developed during and after the heat treatments and are attributed to the heating techniques used.

During construction, no major problems or defects were evident in the adjacent control deck.

DECK EVALUATIONS

Comparative evaluations of the ISC overlays and the adjacent control deck were made at four times after the heat treatment. The first two, in March 1978 and April 1979, were made at 5 and 18 months after construction. The third was made during 1981, two winters after the decks had been opened to traffic in June 1979, and the last one in May 1983, after four winters of exposure to traffic.

The evaluations consisted of visual surveys, hammer and chain drag soundings, determinations of chloride contents, and measurements of half-cell potentials.

First Evaluation

The first evaluation was described in some detail in the first interim report.(2) Visual surveys and soundings on the ISC and the control decks showed no defects or delaminations. Cracks observed during the heat treatment had closed tightly and were not readily visible to the unaided eye.

Samples taken from the decks to determine the background chloride contents showed values of 0.68 lb.Cl^-/yd.^{3} (0.40 kg Cl^-/m^3) for the control concretes and 0.45 lb./Cl^-yd.^{3} (0.27 kg Cl^-/m^3) for the ISC. These tests were made in accordance with AASHTO T-260.

Half-cell potentials were measured in accordance with ASTM C 876 using 5-ft. (1.5-m) grids to determine the probability that the reinforcing steel was undergoing corrosion. In these measurements, copper-copper sulfate (CSE) values numerically less than -0.20 volt CSE indicate a 90% probability that no corrosion is taking place, values between -0.20 volt CSE and -0.35 volt CSE indicate uncertainty, and values higher than -0.35 volt CSE indicate a greater than 90% probability that corrosion is occurring. The values obtained for the control deck were all numerically less than -0.20 volt CSE. For the ISC overlays, 79% of the values were numerically less than -0.20 volt CSE and the remainder less than -0.35 volt CSE, which indicates that for 21% of the deck there was uncertainty concerning corrosion of the steel. In the second evaluation, however, it was shown that corrosion was not occurring.

Second Evaluation

The second evaluation, which was also prior to opening the structure to traffic, was described in a report submitted in August 1979.(4) A visual survey of the control decks revealed very few cracks possibly attributable to plastic shrinkage. A larger number of cracks were now readily visible on the deck with the ISC overlays. A majority of these cracks were attributed to the thermal effects resulting from heat treatment; some, however, may have been caused by plastic shrinkage.

Hammer and chain drag soundings on the control and experimental decks revealed a delamination at one small area about 6 in. (150 mm) in diameter in the center span of the experimental deck. It is possible that this delamination was present when the earlier evaluation was made but was missed due to its small size.

During the second evaluation, determinations of chloride contents were not deemed to be necessary because the decks, not having been opened to traffic, had not been subjected to applications of deicing salts. Half-cell potentials measured on both bridges were numerically less than -0.20 volt CSE, which indicated no corrosion in either bridge. At the earlier evaluation like measurements had indicated uncertainty about corrosion activity in 21% of the experimental deck. However, based on the second evaluation, it can be assumed that no corrosion of the top reinforcement had occurred in either deck at the time they were opened to traffic.

Third Evaluation

The third evaluation was made after the decks had carried traffic for two winters and was detailed in a report issued in 1981.[5] The visual survey of the control decks showed a few cracks that possibly could be attributed to plastic shrinkage. The experimental deck exhibited a significant amount of cracks that were attributed mainly to thermal effects from the heat treatment. The abundance of cracks on the ISC deck had also been evident a year earlier (March 1980) when close-range terrestrial photogrammetry was used to determine the crack lengths. The cracks were classified into two groups, according to their widths, and it was found that those smaller than 0.04 in. (1 mm) wide totaled 112 ft. (34 m) as measured from the plan views and that those wider totaled 219 ft. (67 m).

Hammer and chain soundings of the control deck in January 1981 revealed no delaminations. However, the experimental deck exhibited 145 $ft.^2$ (13.5 m^2) of delaminated areas, which were about 3% of the total deck surface.

Chloride contents were determined on samples taken in April 1981, 42 months after the heat treatment. Two-inch (50-mm) cores were drilled from two locations in each span, one in the traffic lane and the other in the passing lane, of the decks. The chloride contents were determined at two levels: D1 extending from a depth of 0.5 in. (13 mm) to 1 in. (25 mm) and D2 from 1.5 in. (38 mm) to 2 in. (50 mm). The calculated values were corrected for background chloride and are summarized in Table 1. All the values for both decks were below the total chloride corrosion threshold value of 1.3 lb. $Cl^-/yd.^3$ (0.77 kg Cl^-/m^3) of concrete, even though the samples from the experimental deck generally exhibited slightly higher values.

The results of half-cell potential values obtained in September 1981, 47 months after the heat treatment, are summarized in Table 2. For the control deck, all the values being numerically less than -0.20 volt CSE, indicated no corrosion activity. In the experimental deck, however, spans 1 and 2 had 19% and 6% of each surface, respectively, in the uncertain range of corrosion activity, and half-cell potentials indicated that corrosion was occurring in 1% of the area of span 1.

Table 1

Chloride Contents in lb. $Cl^-/yd.^3$

Span			Traffic Lane				Passing Lane			
			42 Mo.		67 Mo.		42 Mo.		67 Mo.	
Type	No.	Location	D1*	D2**	D1	D2	D1	D2	D1	D2
Control	1	East	0.0	0.0	2.0	0.3	0.0	0.0	0.9	0.0
	2	Center	.0	.0	2.2	.0	.0	.0	.8	.0
	3	West	.0	.0	1.3	.0	.0	.0	.4	.0
ISC	1	West	.4	.0	.1	.0	.1	.0	.2	.0
	2	Center	.2	.1	.0	.0	.1	.0	.0	.0
	3	East	0.4	0.2	0.0	0.0	0.2	0.0	0.0	0.0

NOTE: 1 lb. $Cl^-/yd.^3$ = 0.59 kg Cl^-/m^3

*D1 = 0.5 to 1.0 in. (13 mm to 25 mm)

**D2 = 1.5 to 2.0 in. (38 mm to 51 mm)

Table 2

Distribution of Half-Cell Potentials in Percent

Span			47 Mo.			67 Mo.		
Type	No.	Location	A*	B**	C†	A	B	C
Control	1	East	100	0	0	98	2	0
	2	Center	100	0	0	87	13	0
	3	West	100	0	0	91	9	0
ISC	1	West	80	19	1	88	11	1
	2	Center	94	6	0	91	9	0
	3	East	100	0	0	96	4	0

*A Below -0.20 volt CSE

**B -0.20 to -0.35 volt CSE

†C Above -0.35 volt CSE

Fourth Evaluation

The fourth evaluation was conducted in May 1983, after four winter exposures from the time the decks were opened to traffic.

Visual Survey and Soundings

A visual examination of the cracks in the control and the experimental decks revealed a few cracks, possibly attributable to plastic shrinkage, in the former, and numerous cracks, attributed mainly to the heat treatment and referred to as thermal cracks, in the latter.

Figure 1 shows typical cracks on the experimental deck at the time of the fourth survey. Quantitative measurements of crack lengths were not made, but it was noted that the crack pattern and the abundance of cracks were similar to what had been observed in the evaluation in April 1981.

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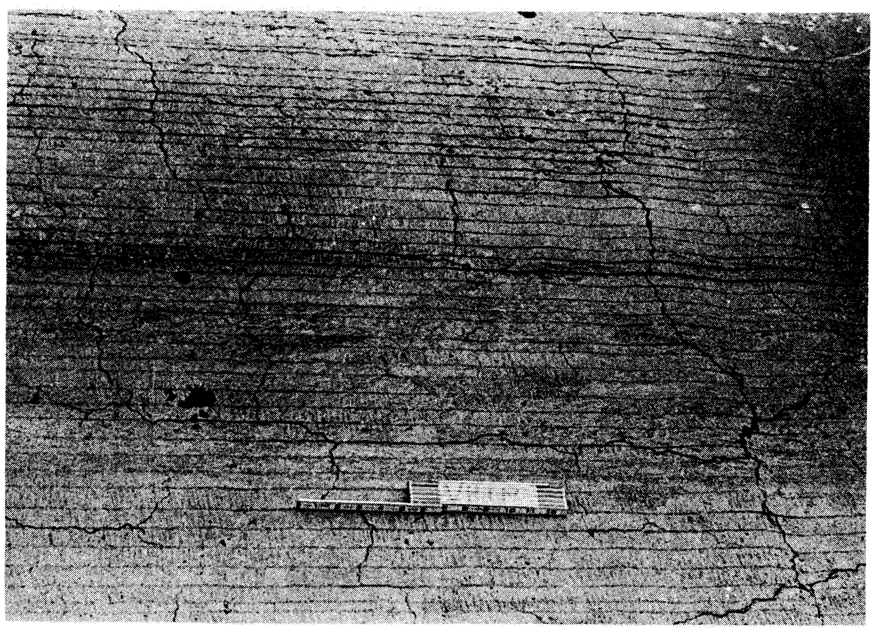

Figure 1. Cracks on ISC deck surface in May 1983, 67 months after heat treatment.

Hammer and chain drag soundings were made, and the control deck was again found to be free of delamination. On the experimental deck, the soundings revealed one small additional area of delamination. However, when the total delaminated area was considered, it was concluded that no significant change from the previous evaluations had occurred.

Chloride Contents

Chloride contents were determined for both bridges, one in each span and in each lane, at two depths as was done in the previous evaluation. The results, summarized in Table 1 under 67 months indicated that chloride contents at the 0.5 in. to 1 in. (13 mm to 50 mm) depth in the traffic lanes on the control deck were at or above the corrosion threshold value. Values at the same depth for the passing lanes were below the threshold value. In the lower depth of 1.5 in. to 2 in. (38 mm to 50 mm), no chloride from deicer salts was found, except in one case, where it was very low. In the ISC, the chloride contents at the upper depth were very small, and at the lower depth were not measurable. Thus no value high enough to initiate corrosion was found; however, chlorides had started penetrating the upper layer of the control concrete.

To investigate the effect of cracks in the ISC on the penetration of chlorides, six samples, two from each span, were obtained at the 1.5 in. to 2.0 in. (38 mm to 50 mm) depth. Three of the samples were taken in areas where the surface cracks were less than 0.04 in. (1 mm) wide and the remaining three at locations where the cracks were wider than 0.04 in. (1 mm). From Table 3 it can be seen that one sample out of the three representing each crack width had a chloride content equal to or greater than the corrosion threshold value. While the remaining samples exhibited very small amounts of chlorides, these results do suggest that cracks can facilitate the intrusion of chlorides to the level of the steel.

Half-Cell Potentials

A summary of the half-cell potentials determined at 67 months was given previously in Table 2. At this age, the values for the control deck gave the first indication of uncertainty about the corrosion activity of the steel in some areas; however, there stil was no indication of corrosion activity in most of the areas. Also, it should be noted that the reinforcing bars in the control deck are epoxy coated and no significant corrosion is expected. On the experimental ISC deck, the half-cell potentials indicated uncertainty about corrosion activity in some areas and that corrosion was occurring in 1% of the total surface area. These results for the ISC do not indicate a significant change from the April 1981 evaluation.

Table 3

Chloride Contents in lb. $Cl^-/yd.^3$ at Cracked Locations in the ISC Deck

	Crack Width	
Span	< 1 mm	> 1 mm
1	0.1	1.3
2	1.8	0.2
3	0.3	0.2

NOTE: 1 lb.$Cl^-/yd.^3$ = 0.59 kg Cl^-/m^3

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CONCLUSIONS

The conclusions drawn from the laboratory and field evaluations are as follows:

1. The laboratory studies showed that for proper freeze-thaw resistance, the ISC required from 4% to 6% of entrained air. The compressive strengths of these concretes were adequate, even though a 5% reduction in strength occurred after heating. The intrusion of chlorides into ISC was negligible.

2. The results of tests on samples of ISC obtained during construction of the bridge decks were similar to those for laboratory samples.

3. The field investigation of the ISC revealed that the heat treatment used led to numerous cracks in the surface of the deck.

4. In addition to being unsightly, these cracks could facilitate the intrusion of chlorides and thus defeat the purpose for using ISC. Chloride contents at or above the corrosion threshold values were found at the level of the reinforcing bars at crack locations. The half-cell potentials also indicated areas where the corrosion activity was uncertain, and even a small area where corrosion was occurring. However, the rate of corrosion must be very slow, since no significant change in values occurred between the 1981 and 1983 evaluations. At the time of the 1983 evaluation, the uncracked areas were performing as was expected from the laboratory studies in that intrusion of chlorides into concrete was minimal, even at the 0.5 in. to 1 in. (13 mm to 25 mm) depth.

5. Some delaminations, about 3% of the total area, were observed in the experimental decks. However, no significant change in the amount of delaminations was found over the last 2 years. No delaminations were noted on the control deck.

RECOMMENDATIONS

The internally sealed concrete overlays can prevent the penetration of chlorides. However, the heat treatment used with these concretes needs to be improved, since there are indications that the numerous cracks attributable to the present procedure adversely affect the performance of the ISC. These cracks are also unsightly.

It is recommended that air-entrained ISC be considered as a protective system only if a new heating technique is introduced which eliminates thermal cracks, and if the system is found to be cost-effective compared to the other available methods.

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